# New digital predistortion technique of RF power amplifiers for wideband OFDM signals

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**Abstract:** A new digital predistortion (DPD) technique is presented for the linearization of RF power amplifiers (PAs) for wideband orthogonal frequency division multiplexing (OFDM) signals. The proposed DPD technique employs the phase correction term to compensate for the frequency dependent AM-PM distortion of PAs, considering the wide bandwidth of OFDM signal. The simulation shows that the proposed DPD technique can significantly improve the error vector magnitude (EVM) performance of RF PAs.

**Keywords:** digital predistortion, linearization, OFDM, power amplifier

**Classification:** Microwave and millimeter wave devices, circuits, and systems

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## 1 Introduction

OFDM signal consists of many orthogonal sub-carriers, and each of them is modulated with the conventional digital modulation scheme such as phase-shift keying (PSK) and quadrature amplitude modulation (QAM). Therefore, it can provide high data rate, high spectrum efficiency and robustness in the multipath propagation. The OFDM has been adopted for various wideband communications such as worldwide interoperability for microwave access (WiMAX), long term evolution (LTE), wireless broadband internet (WiBro), wireless local area network (WLAN), digital audio broadcasting (DAB) and digital video broadcasting (DVB) [1, 2]. The modulation bandwidth can be variable from a few MHz to tens of MHz according to the channel conditions [3].

The OFDM signal has high peak-to-average ratio (PAR) greater than 10 dB, which requires large power back-off for linear operation of PAs, resulting in a low average efficiency [4]. The linearization of RF PAs is, therefore, essential for high efficiency as well as the minimization of signal distortion and adjacent channel interference. There have been many researches on the linearization of OFDM PAs [5, 6, 7]. The DPD is one of the promising linearization techniques, since it allows the use of well-developed digital signal processing techniques in the baseband [8]. In general, RF PAs exhibit frequency dependent distortion characteristics, which have been ignored in the narrowband wireless communications. That is, the distorted input in the conventional DPDs is digitally produced based on the extracted AM-AM and AM-PM distortion of PAs at the center frequency only. A new DPD algorithm is proposed in this work by considering the wide bandwidth of OFDM signals. Especially, the phase correction term is introduced in the generation of OFDM signal to compensate for the frequency dependent phase shift of PAs. The simulation shows that the proposed technique can significantly improve the EVM performance of the PA for 20 MHz OFDM input signal.


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## 2 Proposed DPD technique

The baseband OFDM signal $x(n)$ generated in this work has a form of

$$x(n) = \sum_{k=-\frac{N_c}{2}}^{\frac{N_c}{2}} X(k)\exp(j\phi(k))\exp\left(j2\pi n\frac{k}{N_{FFT}}\right) \tag{1}$$

where, $N_c$ and $N_{FFT}$ are the number of sub-carriers and FFT (fast Fourier transform) size, respectively. The $X(k)$ is a complex modulated signal (a 64-QAM in this work) and $X(0)$ is set to be zero. An additional term in Eq. (1), $\exp(j\phi(k))$, represents the proposed phase correction term. It is employed to compensate for the frequency dependent phase shift of RF PA. This term can be determined by investigating the AM-PM performance of PAs with frequency. In this work, the simulation using Agilent ADS is performed to extract the frequency dependent AM-PM performance of a 150-W class-AB GaN PA presented in [9]. It is shown in [9] that the device model developed by the author is accurate enough to well predict the gain, output power, efficiency and linearity performance of the PA. It was designed for W-CDMA basestation at the center frequency of 2.14 GHz. This amplifier is used in this work to verify the proposed idea for 20 MHz OFDM signal. Figs. 1 (a) and (b) show the simulated AM-AM and AM-PM distortion of the PA at 2.13, 2.14, and 2.15 GHz. This simulation frequency covers the bandwidth of OFDM signal, or 20 MHz in this case. The schematic of the designed PA is presented in Fig. 1 (c). The bias condition is as follows: gate bias voltage $V_{gg} = -2.54$ V, drain bias voltage $V_{dd} = 28.0$ V, and drain bias current of 2.47 A. As shown in Fig. 1 (a), the PA exhibits a slight difference in AM-AM performance at high power range depending on the frequency. The AM-PM performance at each frequency is shown in Fig. 1 (b), showing a phase difference; a phase lead by $\phi_d = 4.3°$ at 2.13 GHz and a phase lag by $\phi_d = 4.3°$ at 2.15 GHz, respectively, compared to the phase shift at the center frequency of 2.14 GHz. This value is approximately constant with magnitude of input voltage. Since the modulation signal $X(k)$ is assigned to one of sub-carrier frequencies, this frequency dependent phase shift can be compensated by multiplying the original OFDM signal by $\exp(j\phi(k))$ as in Eq. (1). The $\phi(k)$ in this PA is represented as

$$\phi(k) = \frac{\phi_d}{N_c/2}k \tag{2}$$

It is assumed in Eq. (2) that the PA exhibits a linear phase shift with frequency in the range of the signal bandwidth (20 MHz) as demonstrated in Fig. 1 (b).

Then, the conventional digital predistortion algorithm is performed on the amplitude and phase of the phase corrected OFDM signal $x(n)$ given in Eq. (1), based on the AM-AM and AM-PM distortion of the PA at the center frequency of 2.14 GHz. To correct the AM-AM distortion which is expressed by the function $f(|x|)$ at the center frequency, the magnitude of the distorted


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input is determined as

$$|x_d(n)| = \begin{cases} f^{-1}(A_v|x(n)|), & |x(n)| < x_c \\ |x(n)|, & |x(n)| \geq x_c \end{cases} \tag{3}$$

where, $A_v$ is a target voltage gain after linearization which is lower than the original one at low input powers. The $f^{-1}(|x|)$ is an inverse function of $f(|x|)$, and $x_c$ is the input amplitude satisfying $f(x_c) = A_v x_c$. The phase of the input signal is also distorted to compensate for the phase shift of the PA versus input amplitude. If the AM-PM distortion is described by the function $g(|x|)$ at the center frequency of 2.14 GHz, then, the distorted input $x_d(n)$ is generated as

$$x_d(n) = |x_d(n)| e^{j(\angle x(n) - g(|x(n)|))} \tag{4}$$

where $|x_d(n)|$ is given by the Eq. (3).

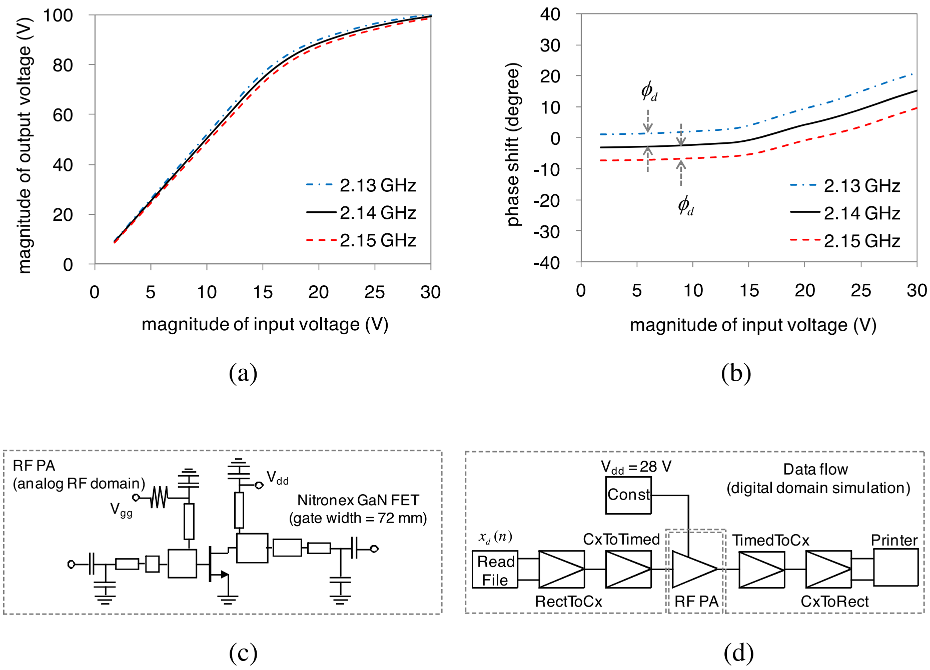


**Fig. 1.** Simulation of the designed GaN PA. (a) Simulated AM-AM performance (magnitude of output voltage versus magnitude of input voltage). (b) Simulated AM-PM performance (phase shift versus magnitude of input voltage). (c) Schematic of the designed PA. (d) ADS Ptolemy simulation setup.

## 3 Verification of the proposed technique

To verify the proposed DPD algorithm, Agilent ADS Ptolemy simulation was performed on RF PA with OFDM signal [10]. It provides the useful DSP algorithms in the baseband for the simulation of modern communication systems. It is also capable of RF analog simulation for the PA. Fig. 1 (d)


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shows the simplified block diagram of the ADS Ptolemy setup. The 64-QAM OFDM signal with 20 MHz bandwidth was generated and digitally distorted according to the proposed DPD algorithm using Matlab. Then, the distorted baseband complex signal $x_d(n)$ is read by ADS (through 'ReadFile' component in Fig. 1 (d)) and converted to time domain RF signal at the center frequency of 2.14 GHz (by 'TimedToCx' component). The generated RF signal is applied to the PA. The PA of which the schematic is shown in Fig. 1 (c) is simulated in analog RF domain using envelope or transient simulation. The output voltage of the amplifier is stored in the form of baseband complex signal (by 'TimedToCx', 'CxToRect' and 'Printer' components). It is finally demodulated using FFT algorithm in Matlab, and EVM is computed by comparing the output IQ data with the original ones.

The simulation was performed for three different inputs; the original input (no DPD applied), the predistorted input without phase correction (that is, a conventional DPD applied), and the predistorted input with phase correction. For fair comparison, the input drive level was slightly adjusted in each case to present the same average output power of 16.2 W and average efficiency of 21.7%. Fig. 2 compares the simulated AM-AM and AM-PM performance of the PA for three different OFDM signal inputs. It is shown in Fig. 2 (a) that the conventional DPD can effectively linearize the AM-AM and AM-PM

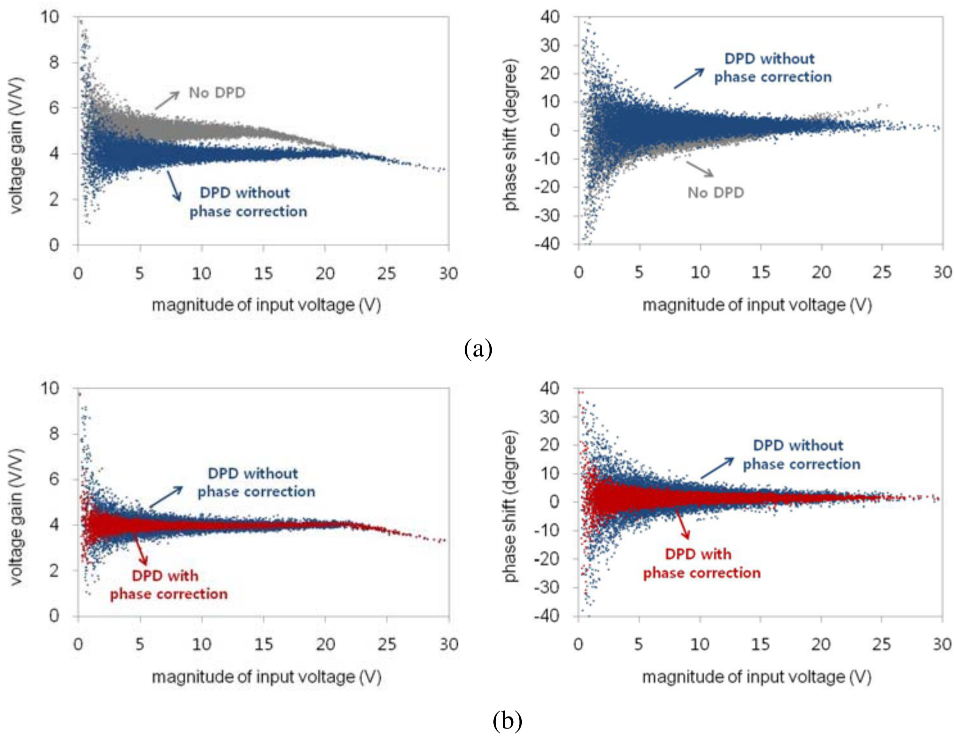


**Fig. 2.** AM-AM (voltage gain vs. magntiude of input voltage) and AM-PM (phase shift vs. magntiude of input voltage): (a) Comparison between no DPD and DPD without phase correction. (b) Comparison between DPD with and without phase correction.


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distortion. The voltage gain is reduced by the DPD as explained in Chap. 2. Fig. 2 (b) demonstrates that the scatterings in the gain and phase are greatly reduced by the proposed phase correction technique. The output spectrum is also shown in Fig. 3 (a), indicating that the proposed DPD technique can effectively reduce the adjacent channel power (ACP), or spectral regrowth. Output spectrum for the conventional DPD technique is not shown in this figure, since it is almost same as the one using the phase correction technique. The excellence of the proposed linearization technique is better presented by the output constellation diagrams as shown in Fig. 3 (b) ∼ (d). The computed EVMs are −24.7 dB for input without DPD, −26.1 dB for DPD input without phase correction, and −32.9 dB for DPD input with phase correction, respectively. This result demonstrates that the proposed phase correction technique can substantially improve the EVM performance.

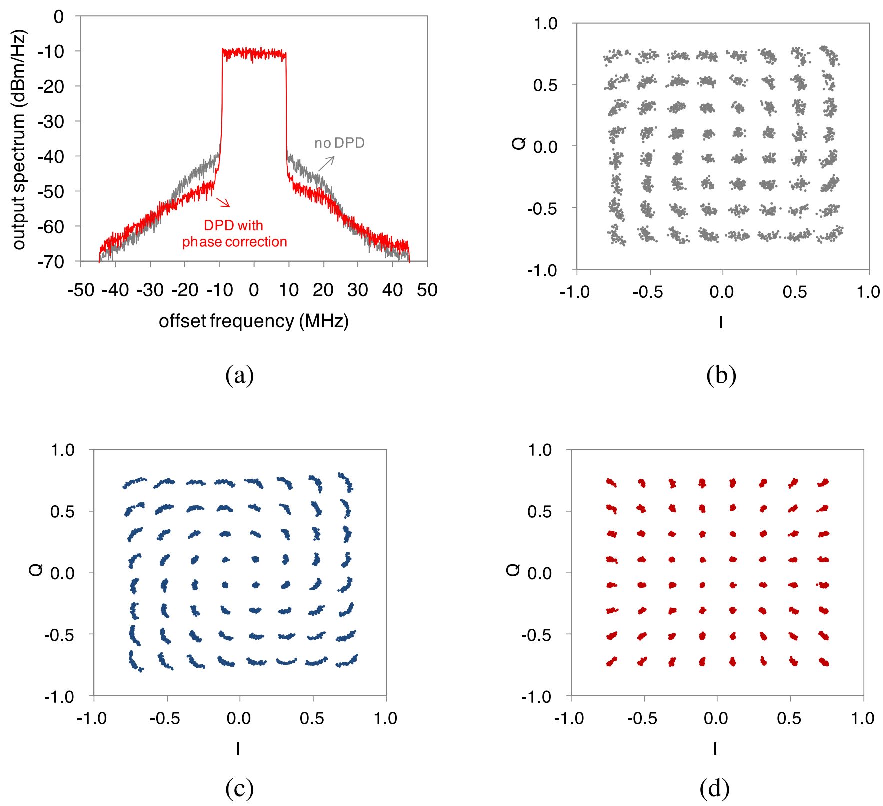


**Fig. 3.** (a) Output spectrum of the PA. Constellation of output signals (64-QAM) with (a) no DPD, (b) DPD without phase correction, and (c) DPD with phase correction.

## 4 Conclusion

In this paper, the new DPD algorithm with phase correction term was proposed for the linearization of RF PAs for wideband OFDM signals. It can correct the frequency dependent phase shift of PAs which cannot be ignored in the signal with wide bandwidth (like tens of MHz at the center frequency


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of a few GHz). It was shown that the proposed technique can effectively improve the EVM performance to meet the stringent specifications of OFDM PAs. It should be noted that the frequency dependent phase variation can be more severe for the PA operating at higher frequency such as 3.5 GHz WiMAX. Therefore, the proposed DPD technique can be effectively applied for the linearization of RF PAs for wideband OFDM signals. The frequency dependent AM-AM distortion should also be corrected for the better performance, which is left as a future work.

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